ATRC
ARIZONA TRANSPORTATION RESEARCH CENTER

RESEARCH NOTES:

Project 557

October 2005

Congestion Mitigation at Railroad-Highway At-Grade Crossings

Several major Arizona highways are located parallel to active railroads. Population growth in the State has been rapid over the last 40 years, and is projected to continue. This growth has occurred both in major cities and towns, pushing them outwards along the State highway routes. This has created many large residential areas that rely on State highways to provide the primary, and often only, daily commuting route.

When a commuter route crosses a railroad line at-grade, trains passing during peak traffic hours often cause congestion that delays traffic and may back queues into adjacent intersections or onto freeways, causing operational and safety concerns for the Arizona Department of Transportation (ADOT). Additional contributing factors to the congestion and safety concerns are the increasing traffic on the railroad lines and the increasing number of these types of crossings, which far outstrip the State's ability to provide grade-separated railroad crossings.

The safety and congestion problems arising from these commuter at-grade crossings are the focus of this research, to investigate these key issues:

<u>Research Question</u>: *Can solutions be applied at a signalized intersection, before a train passes a nearby at-grade highway-railroad crossing, that will mitigate the congestion that will occur after the train has passed? Furthermore, can this be accomplished using a standard traffic signal controller?*

Operational Issues

The current organizational and operating systems of the railroad company and the agency operating the nearby traffic signal have evolved over time, and each may resist change for safety and liability reasons. The railway company owns and operates the gates and lights that comprise the active crossing system that alerts drivers to an approaching train. The traffic signal system at the nearby intersection is owned and operated by the city, county, or state agency that owns the roadway. The railroad's warning control system and the traffic signal control system are not integrated, and operate independently.

It is critical for the nearby intersection traffic signal system to know of an approaching train so that it can take appropriate action to reduce safety problems. This is currently done conceptually by the railroad control system sending a signal to the traffic signal control system indicating a train is approaching the crossing, and later sending another signal that the train has cleared the crossing. When this signal is received, the traffic signal system operates independently to address the safety problems by altering its intersection control scheme in a manner known as train preemption, or simply "preemption."

During preemption, the traffic signal control system interrupts the normal signal timing, clears the tracks of vehicles, and then withholds green on train conflicting movements, giving green to only non-conflicting movements. When the train has passed, it first gives green to the conflicting movements, and then returns to normal operations.

This train preemption control scheme's primary purpose is safety; congestion mitigation is a secondary goal that occurs only after the train has passed. When vehicle volumes over the at-grade crossing are sufficiently large, and/or when the duration and/or frequency of the passing trains is sufficiently high, the preemption control scheme may be insufficient to clear all of the vehicles. This creates congestion that may cause operational problems for the roadway system. Depending on the geometrics involved, vehicle queues may extend back a considerable distance into other intersections, or along freeway ramps onto the freeway itself. In some cases, it can take several cycles for queued vehicles to clear the intersection, causing considerable delay to drivers. The congestion problem is exacerbated if a second train passes before the congestion from the first train clears.

Study Site Geometrics and Traffic

Study site candidates required two primary characteristics: (1) they must be a commuter at-grade crossing and (2) the nearby signalized intersection must be on a State highway. Ideally the site would have severe congestion caused by passing trains. The study site selected was ADOT's Route 66 intersection with Enterprise Road in Flagstaff, Arizona. This site was chosen when the City of Flagstaff became an active secondary sponsor for the research. In retrospect, the intersection proved less than ideal due to its unique geometry and traffic patterns.

The site is a "tee" with Route 66 running east-west, and Enterprise Road as the north-south leg that ends at the intersection. The east-west railroad tracks are parallel to Route 66, and cross Enterprise Road 75 feet south of the intersection.

The normal signal cycle at the intersection has three phases sequencing in this order: (1) WB LT (westbound left turn), WB TH (through), and NB RT (right turn); (2) EB TH and EB RT to move also; and (3) NB TH and NB RT. In the standard NEMA controller used at the site, NB RT operates as an overlap with WB LT and also as an overlap with NB LT. It is allowed to do this by giving it its own phase designation, but this phase only operates as an overlap. Right turns on red after stop are allowed for both the NB RT and the EB RT.

The railroad crossing is owned and operated by the Burlington Northern Santa Fe (BNSF) Railway Company. It is an active crossing using advance-warning signs, crossbucks, pavement markings, bells, gates, and flashing lights. BNSF's control system sends the signal to the intersection traffic signal control system indicating a train is approaching, and another signal indicating the train has cleared the crossing. These signals allow ADOT to begin and end the special train preemption traffic control scheme.

An Early Warning System (EWS) was developed for this study, to address the research question. After applying the EWS to the simulation model developed for the study site, it became apparent that the recent geometric improvements to the study site reduced the congestion sufficiently to mask any congestion mitigation improvement potentially attributable to the EWS. The study site simulation was therefore altered, to reflect its geometry before the recent construction. This changed the study site "tee" intersection to single lanes for NB LT, NB RT, WB LT, and EB RT (a stacking lane). WB and EB through movements are dual lanes. The railroad-crossing model was also simplified to just the two mainline tracks, by eliminating two other infrequently used tracks.

Vehicle traffic data was collected continuously at the site for all movements over a three-day period including counts and videotape. The railroad (BNSF) was a partner in the research, and provided data of all train traffic at the site for a typical seven-day period.

Traffic Simulation Model Development

A VISSIM traffic simulation model was prepared for the study site, and was calibrated and validated using two different data sets extracted from the three days of traffic data. Development of the model was the major portion of the study.

Early Warning System

An ideal EWS would have four characteristics: (1) simple and inexpensive to design, build, and install; (2) easily maintained by existing traffic signal technicians; (3) unilaterally controlled by the highway agency without need for any changes to the railroad control system; and (4) retain the time-tested safety aspects of the current at-grade crossing highway and railroad preemption control systems. The EWS developed for this research contains these four characteristics and uses four subsystems to provide (1) detection, (2) prediction, (3) congestion mitigation, and (4) safety.

Conceptually, two different types of sensor device may be used for the detection subsystem: (1) Doppler radar and (2) time domain reflectometry (TDR). The Doppler radar detector has been used for train detection in previous research. It is pole mounted in a fixed location adjacent to the railroad right-of-way, far from the at-grade crossing. It wirelessly transmits data about a passing train to the traffic signal controller cabinet, where a receiver ports the data to the small EWS field-hardened microprocessor computer that contains the other EWS subsystems.

The TDR sensor was recently developed as part of a Transportation Research Board (TRB) program for a different train application. It is undergoing field-testing and shows promise, but is as yet unproven for this application. TDR induces an electrical pulse into the rails that travels outward until it encounters the wheels of an approaching train. A portion of the pulse is then reflected back; the reflected pulse can be analyzed to provide the train's speed and distance. A TDR detector is located at the crossing itself and the data transmitted to the nearby traffic signal controller via hardwire or wireless.

The EWS prediction subsystem uses an algorithm to predict the arrival time of the train and its passing duration, based on the sensor data. Others have successfully used a simple algorithm, assuming a fixed speed. A fixed speed assumption is valid because the railroad companies strictly enforce train speed limits. The EWS congestion mitigation subsystem is the core of the research and it potentially could decide to take different actions ranging from using different EWS parameters to aborting the use of the system because of uncertainty for that particular train. The model tested different parameters using an EWS algorithm developed for the study. The algorithm was written in the model's macro language, which required a significant effort to develop and refine. In addition, a third-party expert also reviewed the completed algorithm, which confirmed the accuracy of its logic and code.

The algorithm does not impact the safety of the current, time-tested train preemption control scheme. The algorithm always aborts when a train preemption signal is received. This is the same method currently used by NEMA-compliant traffic signal controllers to preempt the normal control sequence when a train arrives. The algorithm is designed to finish all of its operations just as the train preemption signal is received. However, even if it is not finished, the algorithm will always abort when the train preemption signal is received.

Before/After Study Results

Three measures-of-effectiveness (MOEs) were selected for evaluating the effects of the EWS: (1) delay, (2) travel time, and (3) queues. Of these, delay was the primary reporting MOE. Because of the tee intersection geometrics, two intersection movements (parameters) were candidates to receive additional green time before the train arrived: (1) WB LT, which concurrently times WB TH and NB RT and (2) NB LT and NB RT, which time concurrently. The conflicting movements are WB LT, NB LT, and NB RT. Examining these two parameters while varying the other important factors of vehicle traffic flows, train traffic flows, MOE duration period, and train prediction errors, created substantially more cases than resources could accommodate. Therefore, only five cases were selected for testing the EWS. Two to six scenarios were modeled and tested for each case as well as the "no improvements" (before) scenario.

Five major variables were studied by comparing results from the five cases and their multiple scenarios. Crossing gates downtime was varied at three levels: 4.5, 2.6, and 1.5 minutes, based on site train data. MOE results were analyzed at two levels: 15- and 30-minute durations. Conflicting movement vehicle traffic was varied at three levels: actual, twice actual, and three times actual volume. The impact of train arrival prediction error was investigated at three arrival times: 25 seconds early, on-time, and 25 seconds late. Lastly, the impact of the parameters on the queue lengths was examined.

From the perspective of the entire intersection, the overarching before/after results for this site are that the "costs" of the EWS outweigh the "benefits" when intersection delay is considered. The benefits are the savings in delay to the conflicting movements that receive additional green time, while the costs are the increase in delay to the non-conflicting movements that are the donors of additional green time.

Hardware-in-the-Loop Testing

To test the EWS algorithm, a hardware-in-the-loop technique was used with a NEMA controller. This technique linked an actual NEMA controller containing the EWS algorithm to the traffic simulation model. The algorithm was implemented by linking four of the controller's built-in preemptors. The results verified that a microcomputer inside a traffic signal cabinet could send a signal to a standard NEMA controller that would then initiate the appropriate EWS algorithm routine.

Conclusions and Recommendations

Four generalizations appear to be supported by the study results, but more studies at other sites are needed to conclusively verify or dispute them. The first generalization is that the effectiveness of the EWS is highly dependent on the site geometry, and on the vehicle and train traffic volumes. The relative volumes of individual intersection movements are critical because when a conflicting movement is given "extra" green time by the EWS before the arrival of a train, it "steals" that time from other movements. This complex, dynamic interplay is site dependent.

The second generalization is that vehicles must be available to use the "extra" green time before the train arrives. This may not occur unless there were cycle failures before the train arrives. Without these cycle failures, there may not be enough vehicles in or nearing the queue to use the "extra" green time, especially when the "extra" green time is lengthy.

The third generalization is that reducing long queue lengths for safety purposes may justify an increase in overall intersection delay. This may be especially true if the long queues are backing-up into nearby intersections or onto freeways.

The last generalization is that the EWS may be used in other ways to reduce congestion. One example is to send a warning signal to a DMS (dynamic message sign) that alerts drivers of a train's imminent arrival at the crossing, so that they can take an alternate route.

In conclusion, the EWS was ineffective for the study site, but two traffic characteristics may be confounding the results: (1) insufficient pre-train queue lengths for conflicting movements that limit their ability to utilize the "extra" green time; and (2) the lack of a single dominant conflicting flow at the intersection (the study site had fairly balanced cross-flows).

Based on these lessons, a follow-up study is recommended at a new site with favorable geometry and traffic volumes. A multi-phase, incremental study approach should be used that allows termination of the study at the end of any phase that has clearly unfavorable results.

The full report: *Congestion Mitigation at Railroad-Highway At-Grade Crossings* by Craig A. Roberts, Ph.D., P.E., and Jamie Brown-Esplain, Northern Arizona University (Arizona Department of Transportation, report number AZ-05-557, published Dec. 2005) is available on the Internet. Educational and governmental agencies may order print copies from the Arizona Transportation Research Center, 206 S. 17 Ave., MD 075R, Phoenix, AZ 85007; FAX 602-712-3400. Businesses may order copies through ADOT's Engineering Records Section.